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HYPERSONIC HEAT TRANSFER TEST PROGRAM IN THE VKI LONGSHOT FACIL--ETC(U)

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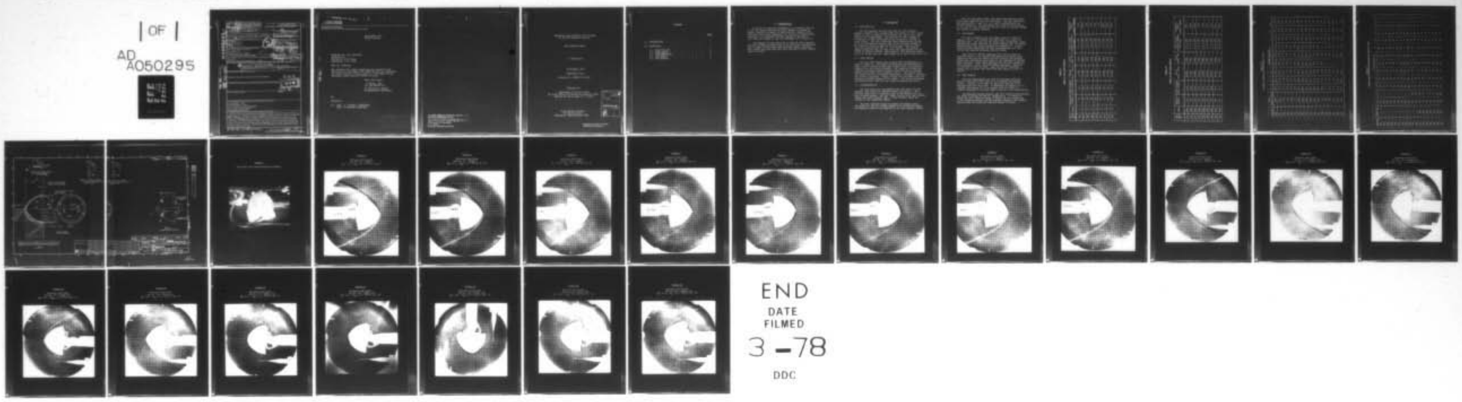

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ROUGHNESS EFFECTS

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A series of tests was performed in the Longshot Facility of the Von Karman Institute of Fluid Dynamics in Rhode-St-Genese, Belgium in support of USAF Grant No AFOSR-76-2942. This post test report summarizes the results of sixteen tests conducted in the Longshot Facility during the periods of 6-17 June 1977 (Phase I) and 5-16 September 1977 (Phase II). The purpose of these tests was to measure local pressure and heat transfer distributions on an ogive body configuration over a range of Mach number and Reynolds number conditions. Both smooth and rough body data were obtained at three degrees angle of attack.

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SYSTEMS DIVISION
201 LOWELL STREET, WILMINGTON, MASSACHUSETTS 01887

28 December 1977
K500-77-VD-200

AFOSR/NA (Mr. Paul Thurston)
Building 410
Bolling Air Force Base
Washington, D. C. 20332

Dear Mr. Thurston:

The enclosed test report summarizes the results of the test series at VKI under Grant AFOSR-76-2942 and represents our final scientific letter report in fulfillment of our agreements under Contract F49620-77-C-0035.

Very truly yours,

V. DiCristina

V. DiCristina, Manager
Thermodynamics Department

mw

Enclosures

cc: Capt. R. Chambers, SAMSO/RSSE
Capt. E. Heinonen, AFML/MXS

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A. D. BLOSE
Technical Information Officer

Hypersonic Heat Transfer Test Program in the VKI Longshot Facility

Test Summary Report

V. DiCristina

21 December 1977

AVSD-0393-77-CR

Contract No. F49620-77-C-0035

Prepared For

Department of the Air Force
Air Force Office of Scientific Research (AFSC)
Bolling Air Force Base, D. C. 20332

Avco Systems Division
201 Lowell Street
Wilmington, Massachusetts 01887

CONTENTS

1.0 INTRODUCTION

A series of tests was performed in the Longshot Facility of the Von Karman Institute of Fluid Dynamics in Rhode-St-Genese, Belgium in support of USAF Grant No. AFOSR-76-2942. This post test report summarizes the results of sixteen tests conducted in the Longshot Facility during the periods of 6-17 June 1977 (Phase I) and 5-16 September 1977 (Phase II).

The purpose of these tests was to measure local pressure and heat transfer distributions on an ogive body configuration over a range of Mach number and Reynolds number conditions. Both smooth and rough body data were obtained at three degrees angle of attack.

2.0 DISCUSSION

2.1 TEST FACILITY

The VKI Longshot facility was used for this program. Longshot differs from a conventional gun tunnel in that a heavy piston is used to compress the nitrogen test gas to very high pressure and temperatures. The test gas is then trapped in a reservoir at peak conditions by the closing of a system of check values. The flow conditions decay monotonically during 10 to 20 milliseconds running time as the nitrogen trapped in the reservoir flows through the 6° half angle conical nozzle into the pre-evacuated open jet test chamber. The maximum supply conditions used in these tests are approximately 60,000 lb/in^2 at 1900° to $2500^{\circ}K$. These provide unit Reynolds numbers of 9.0×10^6 per foot at a Mach number of 16 and 3×10^6 at $M = 20$.

2.2 MODEL DESIGN

The test model design was an ogive body configuration as shown in Figure 1. This model configuration was designated as model K with a smooth surface and as model K(R) with roughness elements over the entire forebody. The roughened surface was created by bonding aluminum spheroid particles onto a sprayed adhesive and coated with a sprayed acrylic. The surface area was coated with 65 mil diameter particles to simulate a turbulent flow surface roughness. Figure 2 shows the test model with the roughness elements bonded to the surface. The local calorimeter and pressure port areas did not contain roughness particles.

2.3 INSTRUMENTATION

The test model was instrumented with both heat flux and pressure taps located at positions shown in Figure 1. The meridian containing the pressure taps is 180 degrees from the heat transfer gauges. The test model contains nine heat transfer gauges and eight pressure taps. A heat transfer gauge was located in the stagnation region.

The heat transfer gauges are smooth calorimeter discs fabricated of .004 inch copper bonded to an insulating holder. No roughness elements were applied to the heat transfer gauges.

Nine new PCB model 112A21 high resolution pressure transducers were supplied with the test model. The new transducers were positioned at taps 2-7, 9, 11 and 13 representing the surface locations. The remaining three pressure tap locations (8, 10 and 12) were blocked off due to a lack of pressure gauges and limited recording capacity.

2.4 TEST MATRIX

The test conditions for the sixteen runs are listed in Tables I and II. Two repeat runs were made for a total of eighteen runs. For each run the actual free stream Mach number and Reynolds number achieved are given together with the corresponding perfect gas total pressure and temperature. A pitot pressure probe measurement is made simultaneously with each run and the measured pressures are also shown.

Runs 570-574, 580-583 represent four sets of tests at angle of attack. A 3^{o} positive and negative incidence angle represents one data set where the heat transfer and pressure gauges were alternately positioned in the windward and leeward flow locations. These tests acquired data for both smooth and rough surfaces at two Reynolds number conditions, nominally 3×10^{6} and 9×10^{6} per foot. Runs 574 and 577 represent repeat runs to obtain lost heat flux data points in runs 573 and 576.

2.5 TEST RESULTS

The data measurements for each run included schlieren photos of the model flow field in the windward and leeward planes. Figures 3 to 20 show the bow shock and flow field structure for each test case. A comparison of Figures 3 to 11 (smooth) and Figures 12 to 20 (rough) show the effect of surface roughness on the flow field structure to be insignificant.

The measured surface pressure and heat transfer distributions are shown in Tables III and IV, respectively. It should be noted that for a positive angle of attack the heat gauges are in the windward position and the pressure gauges in the leeward position and vice versa for negative angles of attack.

Table I

Phase I VKI Test Matrix

VKI Test No.	Model	Angle of Attack	Free Stream Mach Number	Total Press. (psia)	Total Temp (^{o}K)	Free Stream Reynolds Number Per Foot	Measures Pitot Press. (psig)
566	K	0^{o}	15.6	75,900	2420	9.0×10^{6}	27.8
567	K	0^{o}	15.0	41,300	2460	5.3×10^{6}	18.2
568	K	0^{o}	19.5	63,200	3070	2.9×10^{6}	7.8
569	K	0^{o}	19.4	43,600	3130	1.9×10^{6}	5.6
570	K	$+3^{o}$	19.7	70,340	3060	3.1×10^{6}	8.2
571	K	-3^{o}	20.0	72,950	3080	3.1×10^{6}	7.9
572	K	-3^{o}	16.2	84,800	2440	9.1×10^{6}	26.0
573	K	$+3^{o}$	15.6	83,000	2430	9.9×10^{6}	30.6
574	K	$+3^{o}$	15.9	84,200	2460	9.3×10^{6}	28.0

Table II

Phase I VKI Test Matrix

VKI Test No.	Model	Angle of Attack	Free Stream Mach Number	Total Press. (psia)	Total Temp (^oK)	Free Stream Reynolds Number Per Foot	Measures Pitot Press. (psig)
575	K(R)	0^o	15.9	88,800	2480	9.7×10^6	29.4
576	K(R)	0^o	14.8	37,400	2420	5.2×10^6	18.0
577	K(R)	0^o	14.6	36,800	2440	5.1×10^6	18.6
578	K(R)	0^o	19.2	40,300	3040	1.9×10^6	5.4
579	K(R)	0^o	19.5	65,300	3050	3.0×10^6	8.0
580	K(R)	$+3^o$	19.7	69,400	3090	3.0×10^6	8.2
581	K(R)	-3^o	19.6	68,100	3050	3.1×10^6	8.3
582	K(R)	-3^o	16.0	80,600	2380	9.2×10^6	26.1
583	K(R)	$+3^o$	16.0	93,300	2530	9.6×10^6	30.0

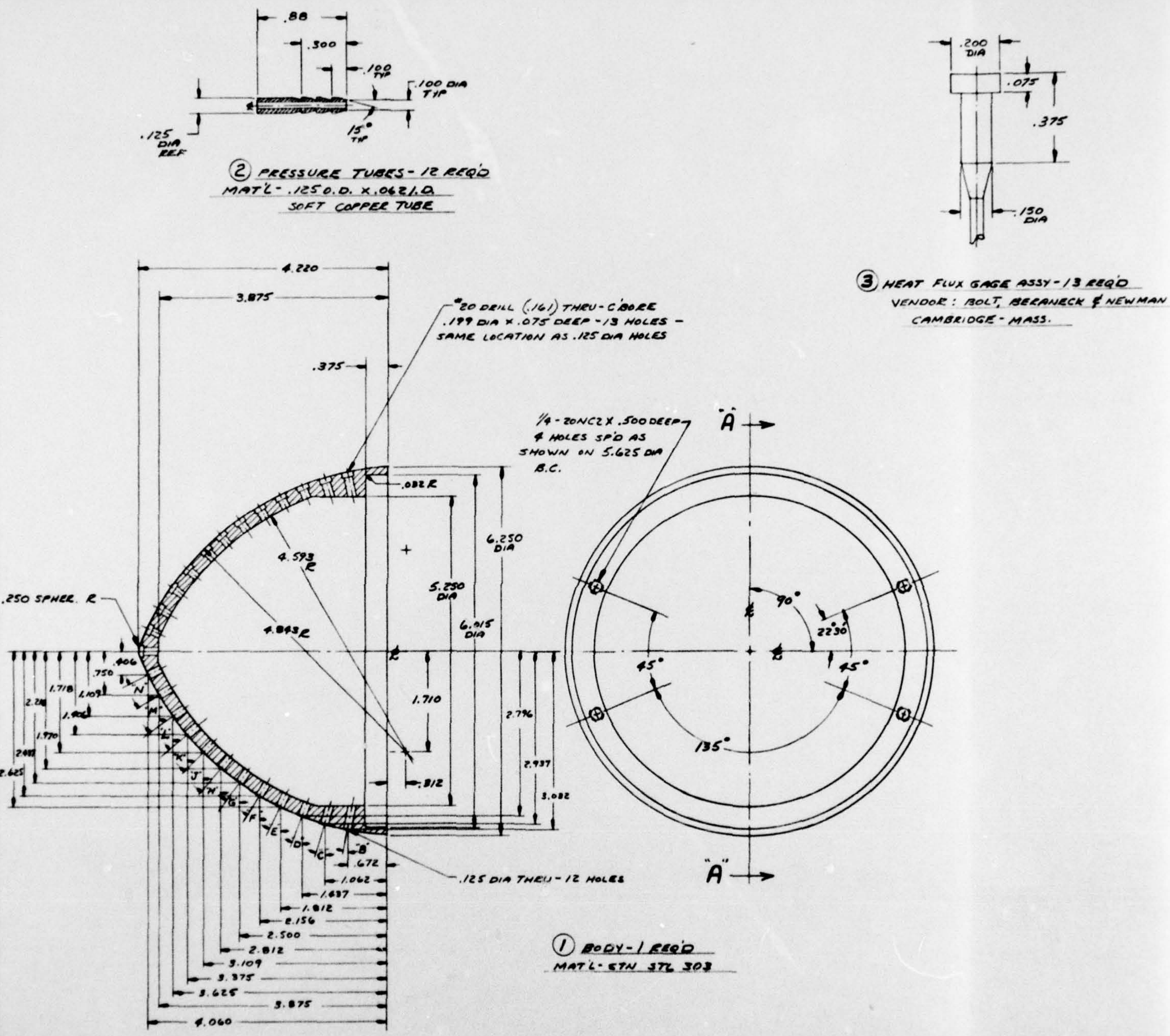
Table III
Surface Pressure Measurements (Psia)

Run No.	Pitot Press. (Pt_2)	Gauge Location								
		2	3	4	5	6	7	9	11	13
566	27.8	20.4	18.5	16.8	13.9	9.8	8.9	5.7	3.0	1.4
567	18.2	14.3	11.6	11.2	9.2	6.5	5.3	3.5	1.9	0.9
568	7.8	6.7	5.8	5.0	3.9	3.0	2.5	1.6	0.9	0.5
569	5.6	4.5	4.3	3.5	2.8	2.4	2.0	1.2	0.7	0.3
570	8.2	6.2	5.7	4.4	3.7	3.1	2.2	1.5	0.8	0.4
571	7.9	7.0	6.8	5.4	4.5	3.1	3.0	2.0	1.2	0.6
572	26.0	23.3	18.4	18.6	14.4	11.3	10.3	6.8	3.7	1.8
573	30.6	20.9	19.2	15.9	13.7	11.2	8.1	5.2	2.6	1.1
574	28.0	19.7	18.0	14.1	12.6	10.0	7.5	4.7	2.4	1.1
575	29.4	20.0	18.3	14.2	14.5	11.3	8.8	6.0	4.5	1.7
576	18.0	14.8	11.0	10.4	8.2	7.9	6.6	3.0	2.0	1.1
577	18.6	14.9	12.5	9.9	9.3	7.8	6.0	3.5	2.0	1.2
578	5.4	4.6	4.2	3.4	2.5	2.3	--	1.2	0.6	0.3
579	8.0	7.7	5.2	5.9	--	3.4	2.7	1.9	1.0	0.5
580	8.2	6.8	5.5	5.8	--	3.6	3.0	2.0	1.2	0.7
581	8.3	6.3	5.1	5.1	--	3.4	2.0	1.5	0.8	0.4
582	26.1	17.1	16.3	15.8	--	10.7	6.6	4.5	2.3	1.3
583	30.0	22.5	18.5	18.0	--	12.4	9.3	6.9	4.1	2.3

Table IV

Surface Heat Transfer Measurements (Btu/ft^2 sec)

	Gauge Location											
Run No.	Stag. pt.	2	3	4	5	6	7	8	9	10	11	12	13
566	--	217	--	179	210	151	137	132	103	56	45	37	3
567	--	220	--	109	140	142	118	105	94	50	45	26	3
568	--	189	--	87	94	84	70	52	37	24	26	14	2
569	--	143	--	73	89	41	39	38	26	15	15	11	--
570	--	232	--	122	111	96	86	57	45	24	23	20	1
571	--	209	--	94	88	84	72	56	41	19	19	12	1
572	--	316	--	187	219	200	154	171	138	53	51	40	1
573	--	300	--	200	300	229	185	115	--	73	64	57	--
574	--	351	--	181	261	210	168	133	122	84	76	61	--
575	--	142	115	85	107	78	77	54	36	29	21	17	11
576	--	193	149	112	104	--	81	--	--	34	28	21	13
577	388	124	120	94	75	79	80	45	25	23	24	16	2
578	345	99	61	46	38	54	39	26	20	12	8	2	1
579	298	107	--	62	73	84	59	29	29	20	11	3	1
580	425	101	85	67	64	71	53	31	51	21	9	5	1
581	349	101	87	91	85	89	66	44	71	16	22	11	1
582	453	108	156	133	117	160	120	81	60	46	32	27	3
583	558	189	189	161	122	170	133	64	67	43	37	11	--



α°											
"B"	"C"	"D"	"E"	"F"	"G"	"H"	"J"	"K"	"L"	"M"	"N"
11°45'	16°30'	21°15'	26°	30°45'	35°30'	40°15'	45°	49°45'	54°30'	59°15'	64°

VIEW "A"-"A"

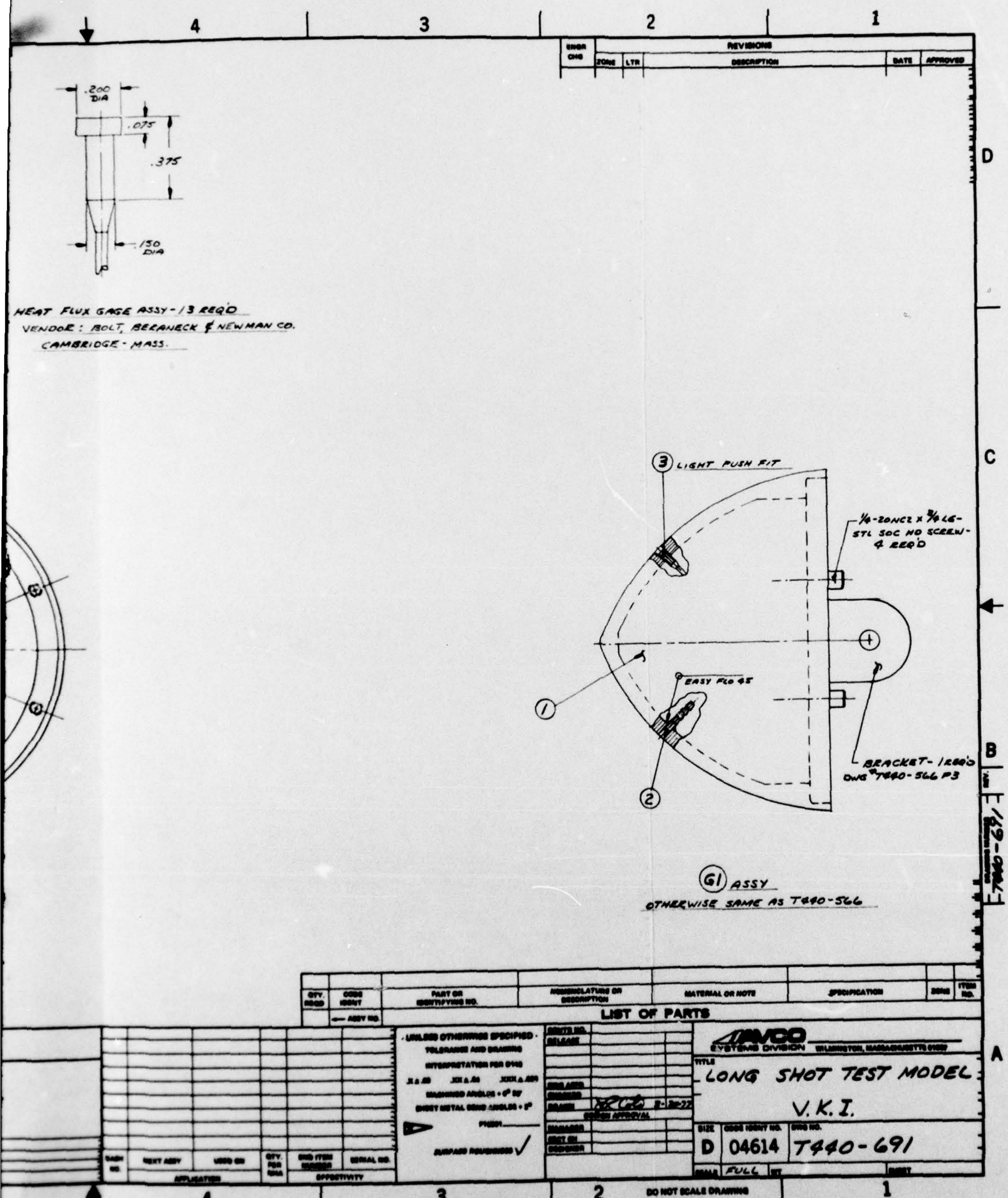


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Figure 2

Test Model With Bonded Roughness Elements

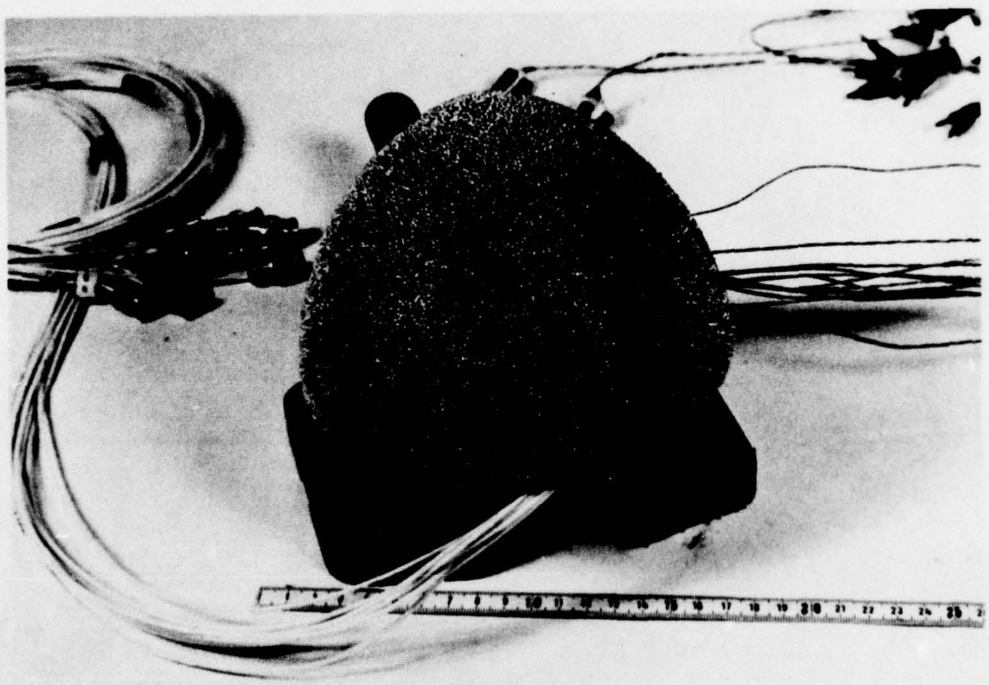

Figure 3

Schlieren Flow Field
Run No. 566 - Model K
$M_{\infty} = 15.6$, $R_{e\infty} = 9.0 \times 10^6$/ft, $\alpha = 0^\circ$

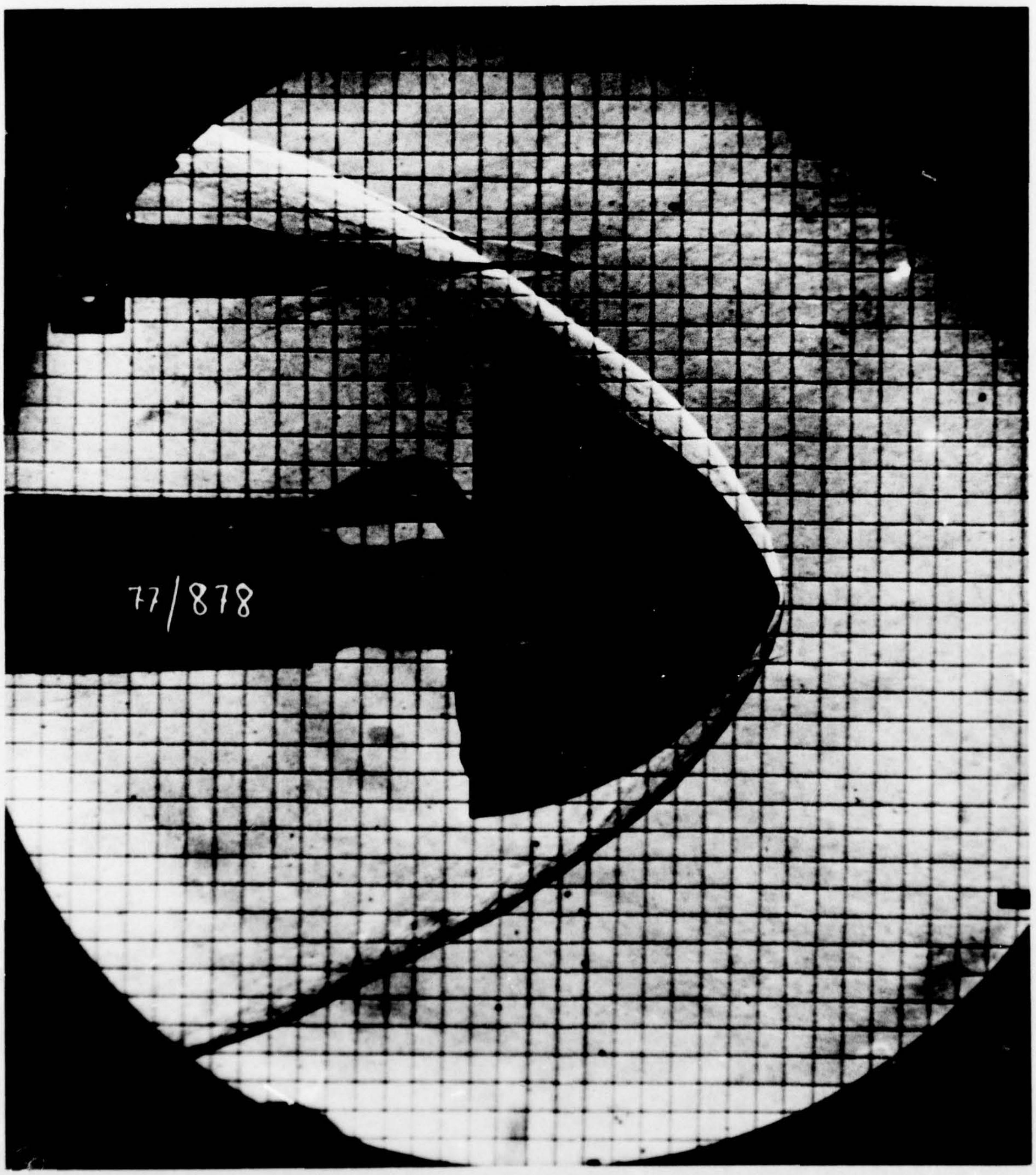

Figure 4

Schlieren Flow Field
Run No. 567 - Model K
$M_\infty = 15.0$, $Re_\infty = 5.3 \times 10^6/ft$, $\alpha = 0^\circ$

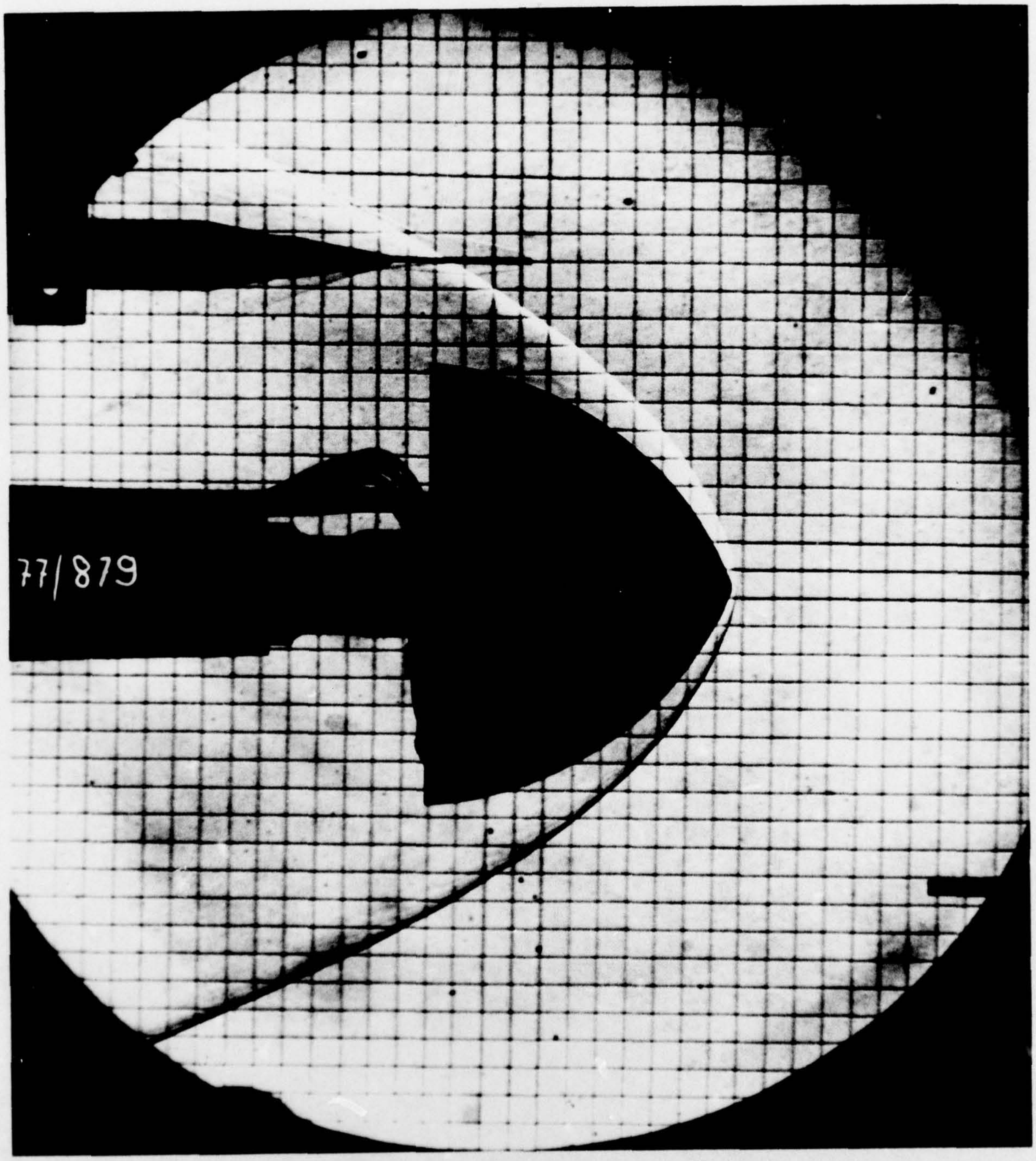

Figure 5

Schlieren Flow Field

Run No. 568 - Model K

$M_{\infty} = 19.5$, $R_{e_{\infty}} = 2.9 \times 10^6$/ft, $\alpha = 0^{\circ}$

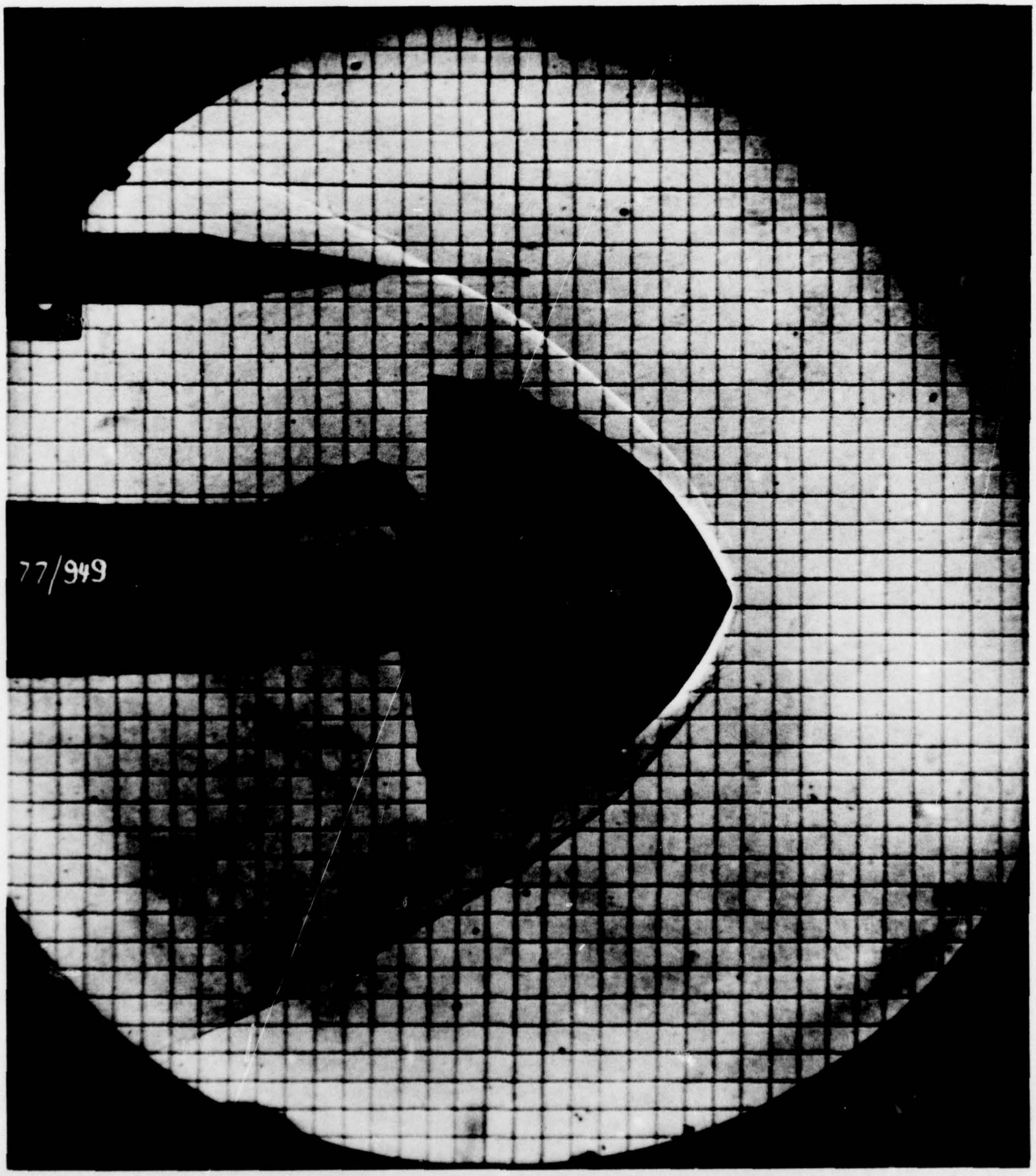

Figure 6

Schlieren Flow Field
Run No. 569 - Model K
$M_\infty = 19.4$, $Re_\infty = 1.9 \times 10^6/ft$, $\alpha = 0^\circ$

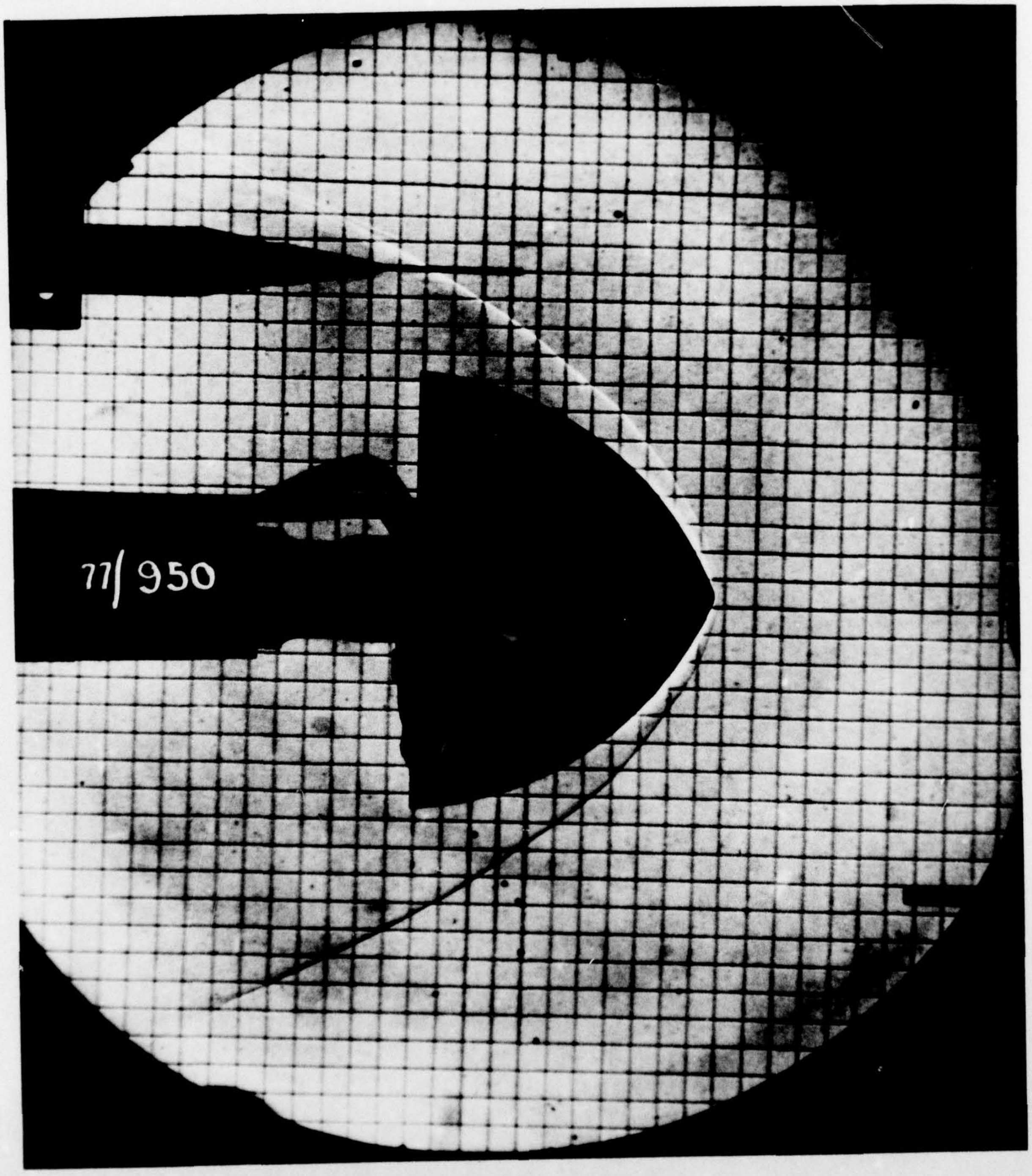

Figure 7

Schlieren Flow Field
Run No. 570 - Model K
$M_\infty = 19.7$, $Re_\infty = 3.1 \times 10^6$/ft, $\alpha = +3^\circ$

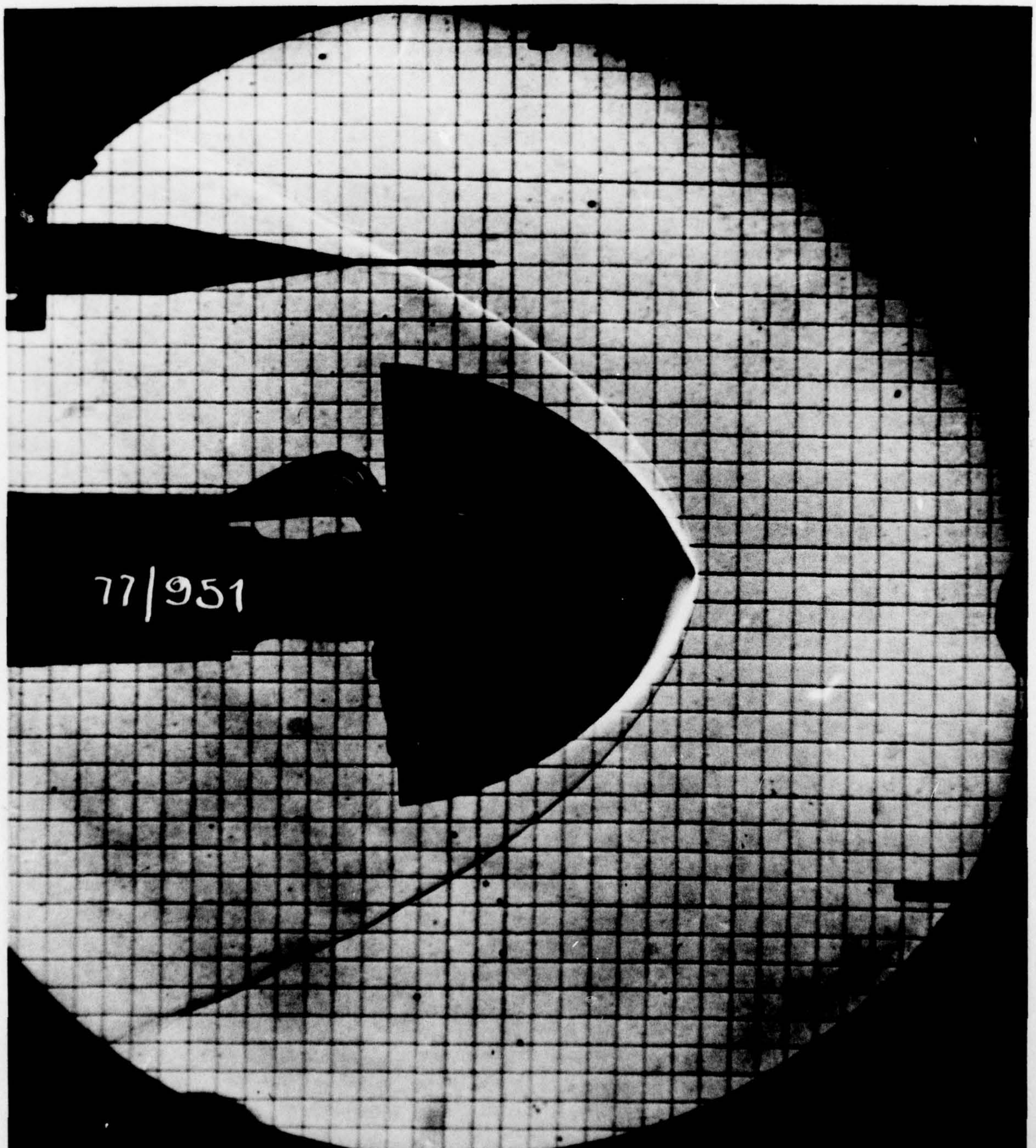

Figure 8

Schlieren Flow Field
Run No. 571 - Model K
$M_\infty = 20.0 \quad R_{e_\infty} = 3.1 \times 10^6/\text{ft}, \alpha = -3^\circ$

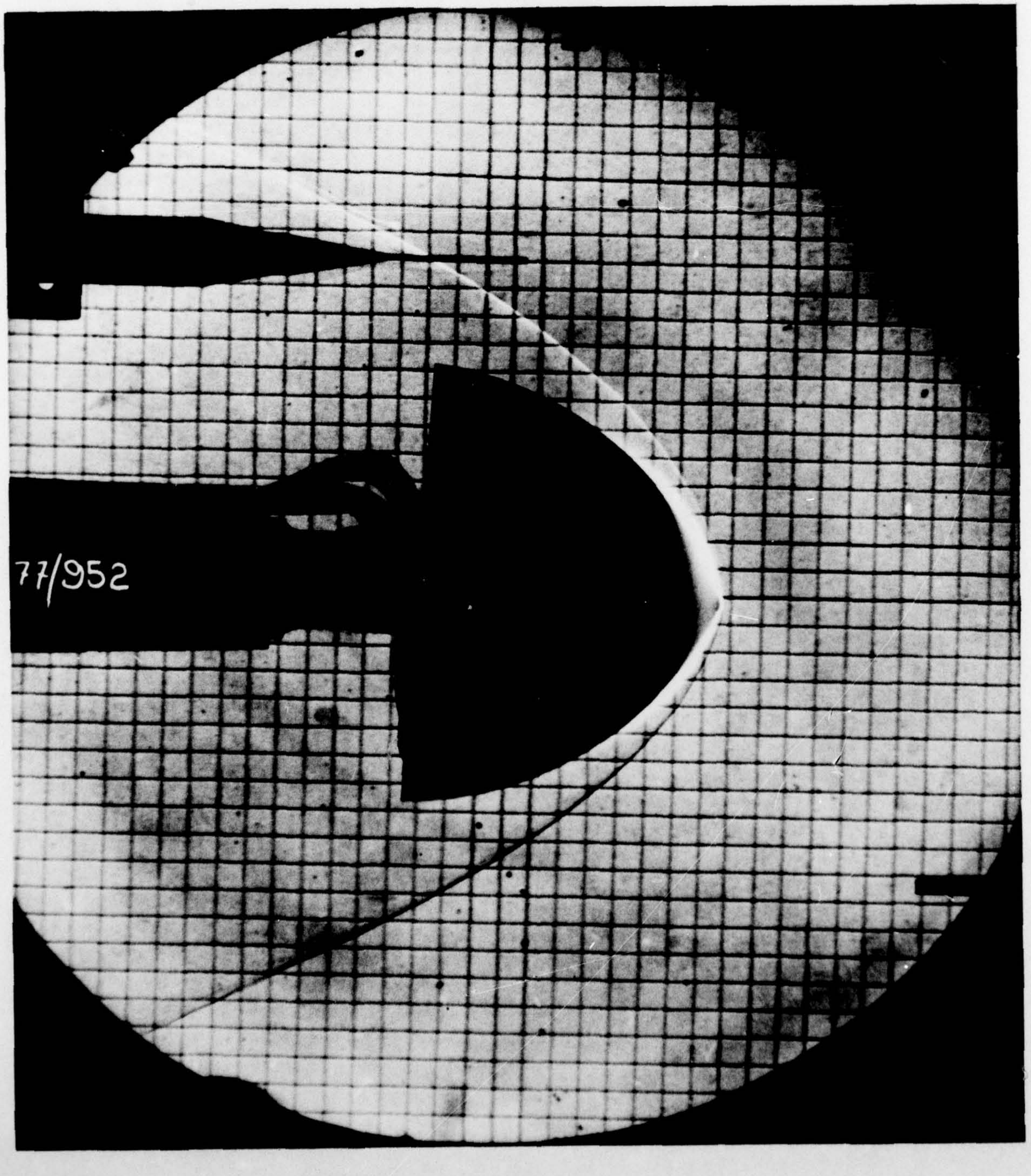

Figure 9

Schlieren Flow Field
Run No. 572 - Model K
$M_\infty = 16.2$, $R_{e_\infty} = 9.1 \times 10^6/\mathrm{ft}$, $\alpha = -3^\circ$

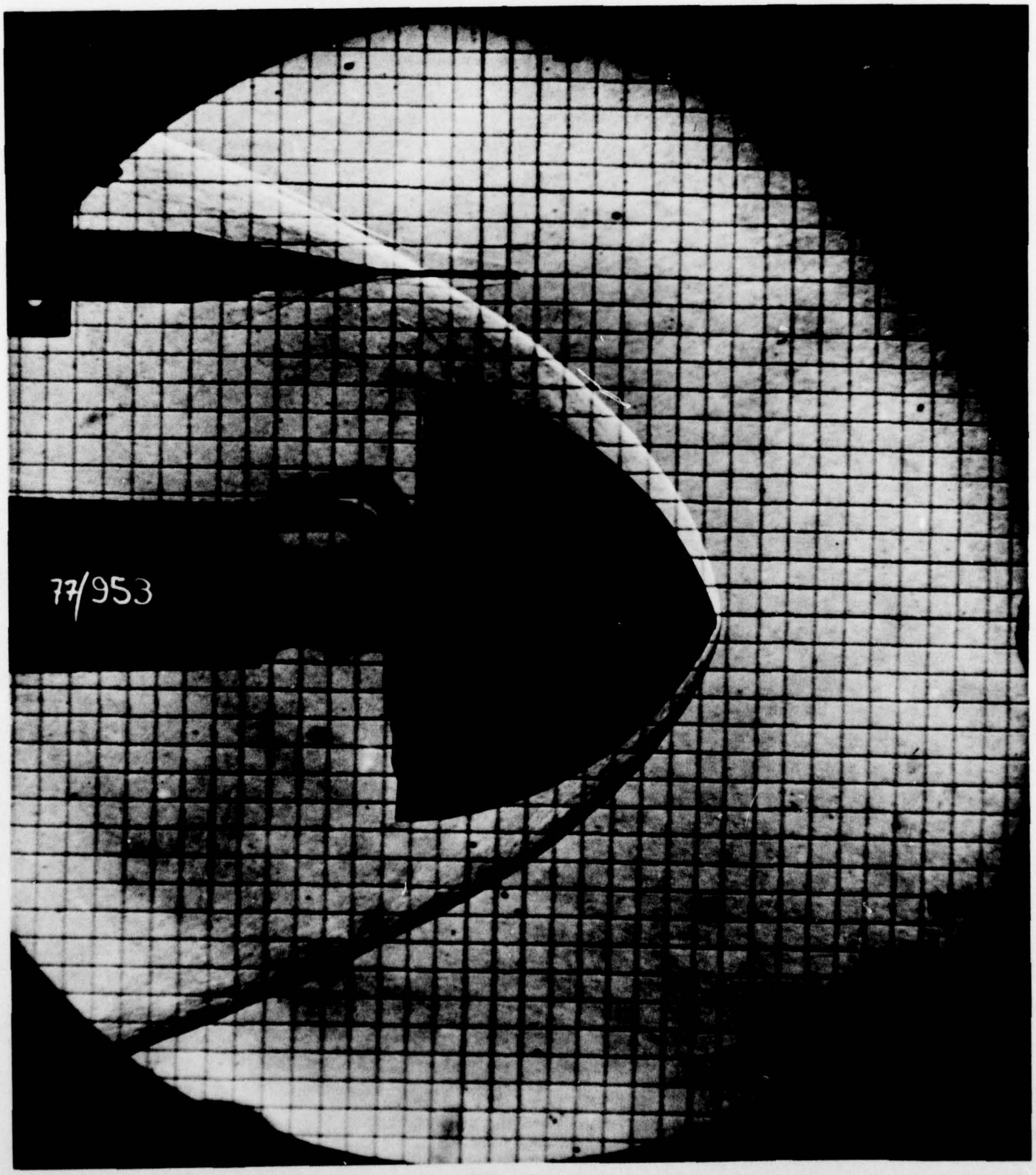

Figure 10

Schlieren Flow Field
Run No. 573 - Model K
$M_\infty = 15.6$, $R_{e\infty} = 9.9 \times 10^6/\text{ft}$, $\alpha = +3^\circ$

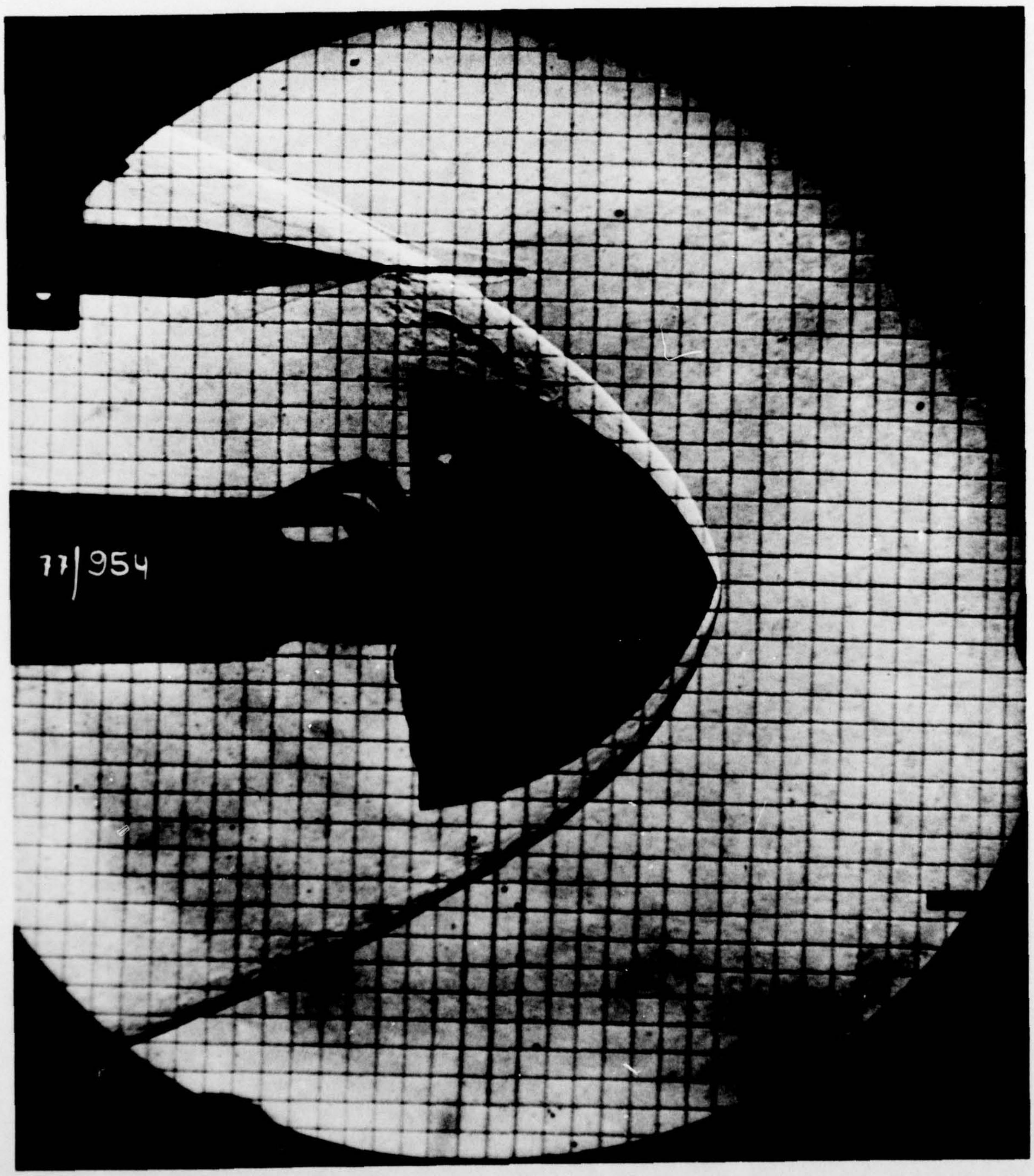

Figure 11

Schlieren Flow Field
Run No. 574* - Model K
$M_{\infty} = 15.9$, $Re_{\infty} = 9.3 \times 10^6/\text{ft}$, $\alpha = +3^{\circ}$

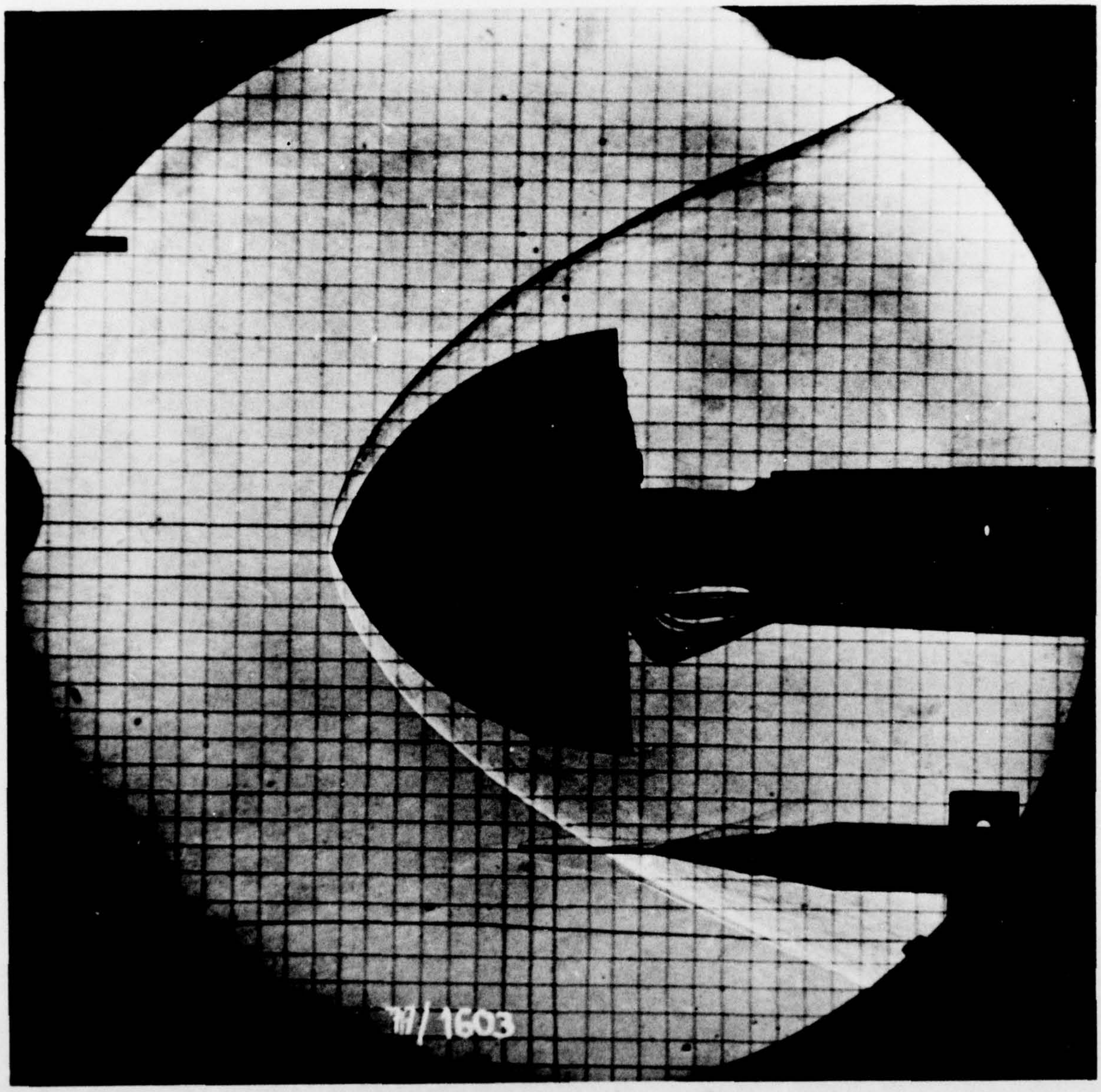

Figure 12

Schlieren Flow Field
Run No. 575 - Model K(R)
$M_\infty = 15.9$, $Re_\infty = 9.7 \times 10^6/ft$, $\alpha = 0^\circ$

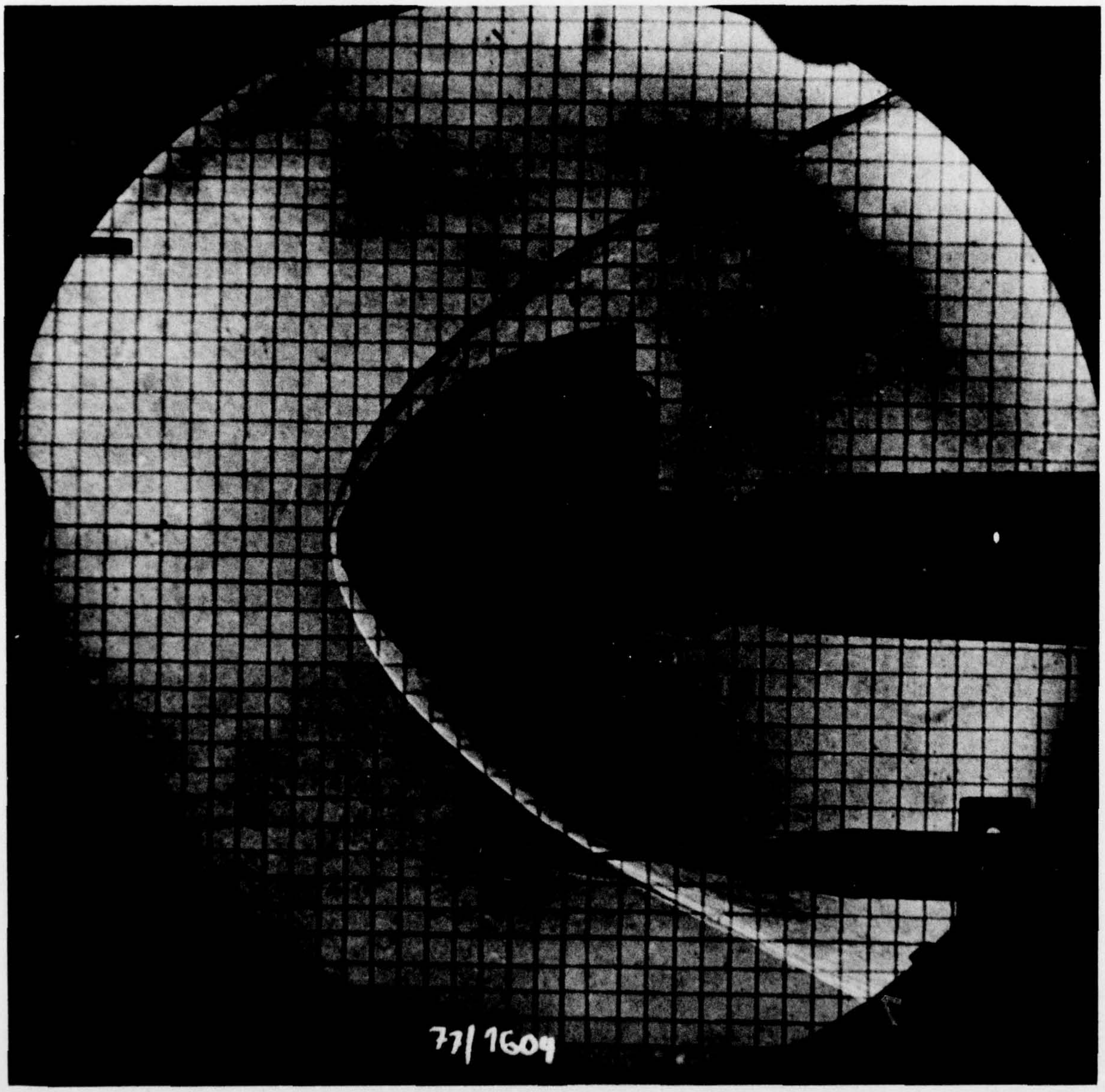

Figure 13

Schlieren Flow Field
Run No. 576 - Model K(R)
$M_{\infty} = 14.8, \quad R_{e_{\infty}} = 5.2 \times 10^6/ft, \quad \alpha = 0^{\circ}$

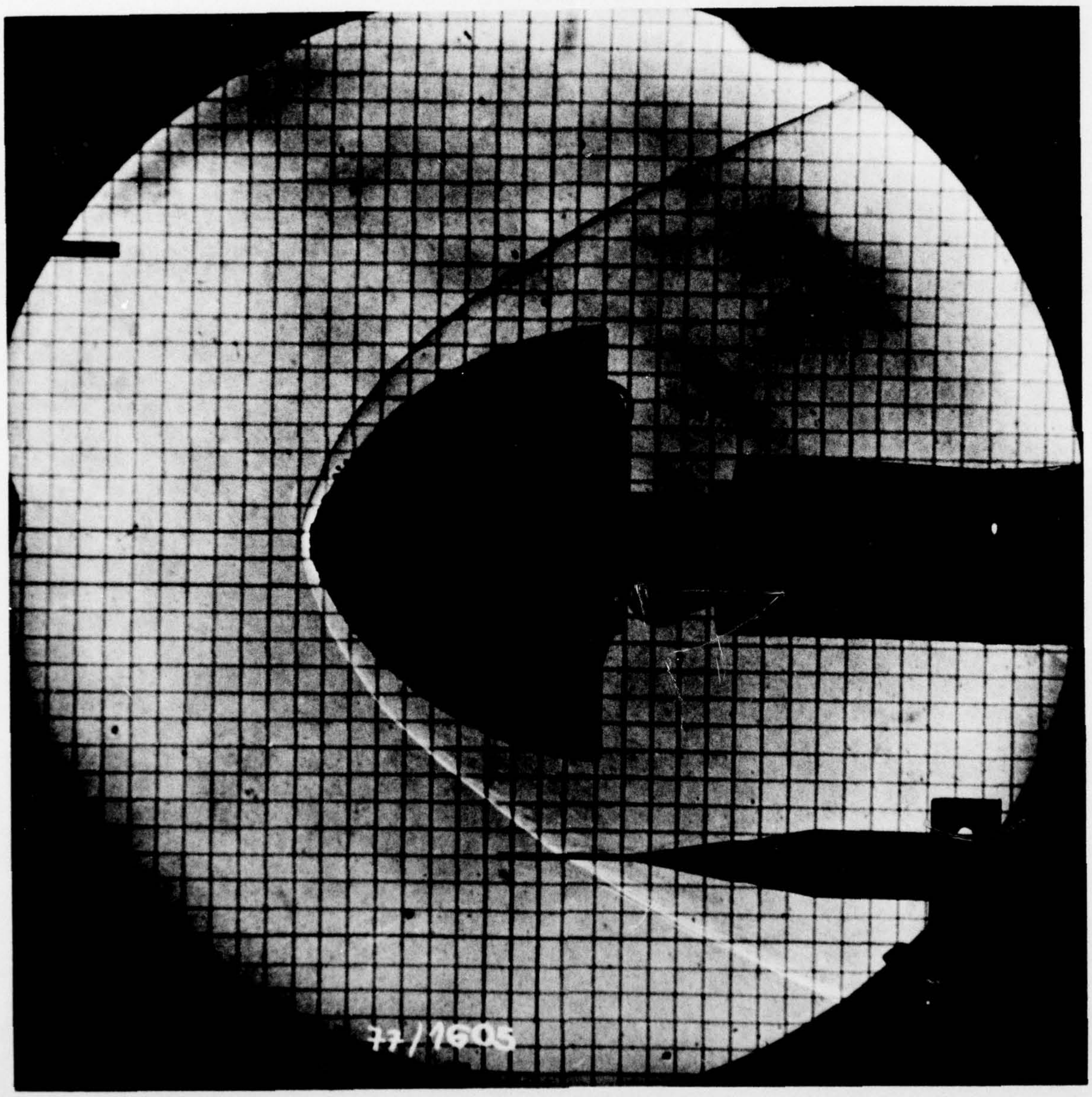

Figure 14

Schlieren Flow Field
Run No. 577 - Model K(R)
$M_\infty = 14.6$, $R_{e_\infty} = 5.1 \times 10^6$/ft, $\alpha = 0^\circ$

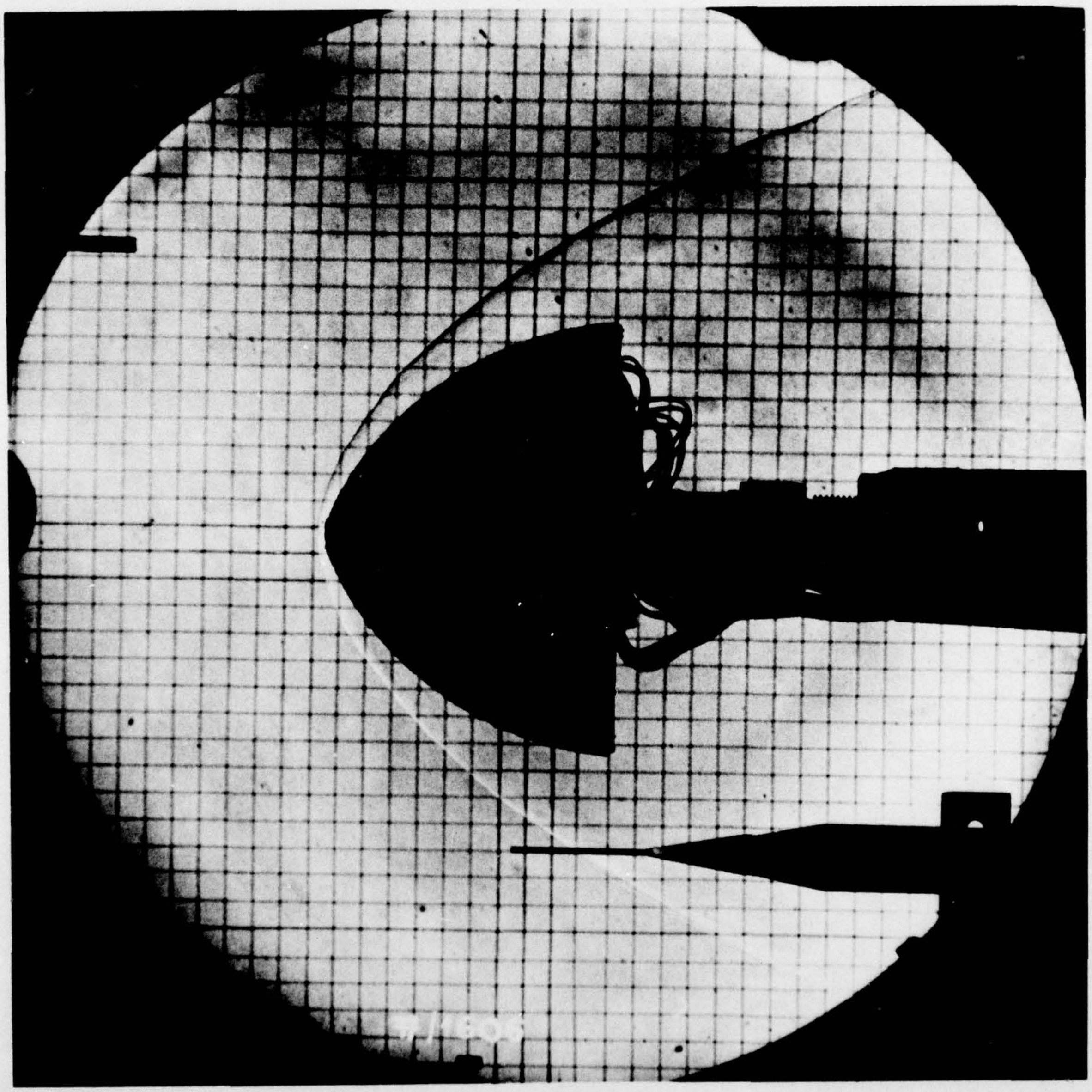

Figure 15

Schlieren Flow Field

Run No. 578 - Model K(R)

$M_{\infty} = 19.2$, $R_{e_{\infty}} = 1.9 \times 10^6/\text{ft}$, $\alpha = 0^\circ$

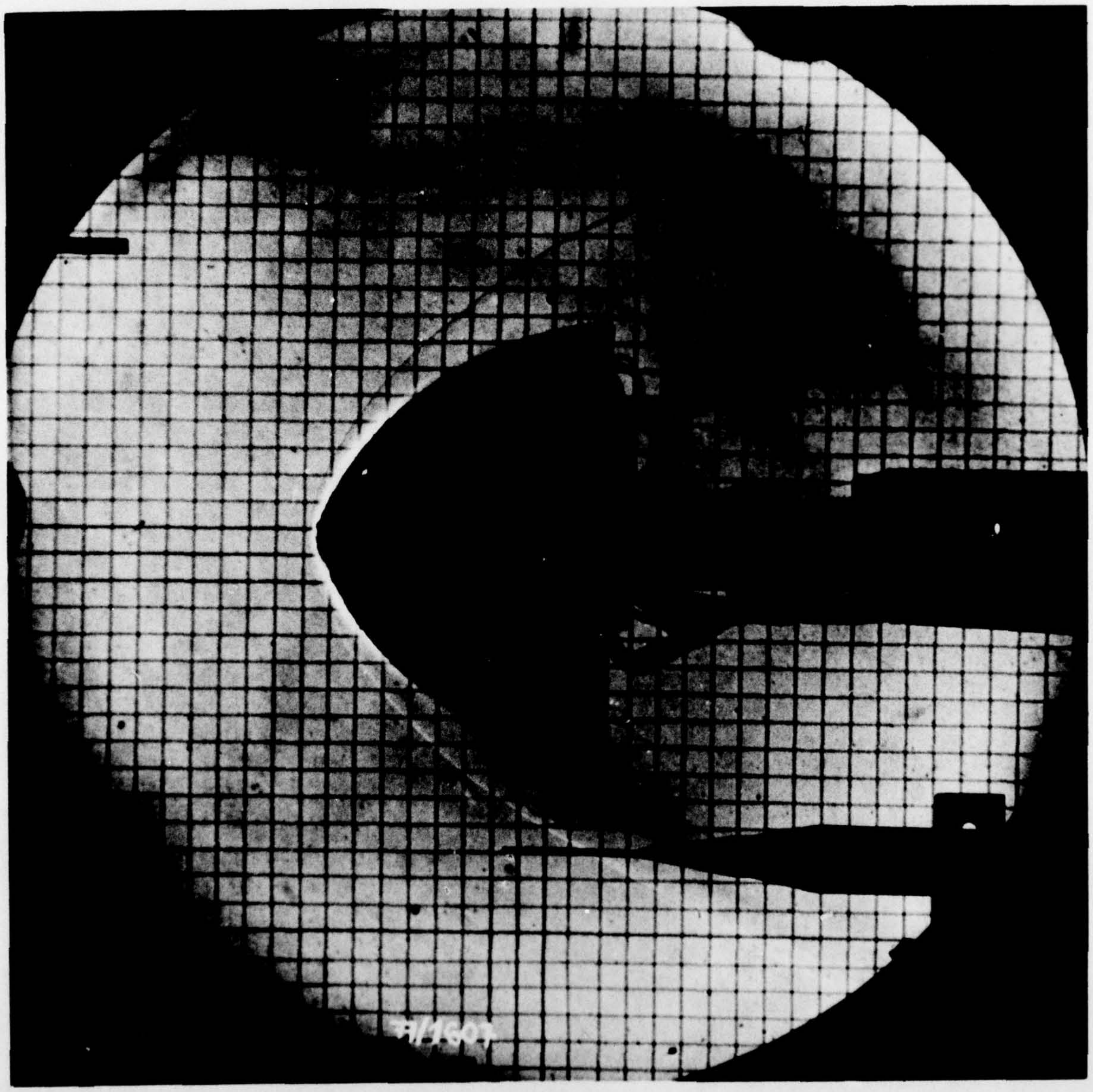

Figure 16

Schlieren Flow Field
Run No. 579 - Model K(R)
$M_\infty = 19.5$, $Re_\infty = 3.0 \times 10^6/ft$, $\alpha = 0^\circ$

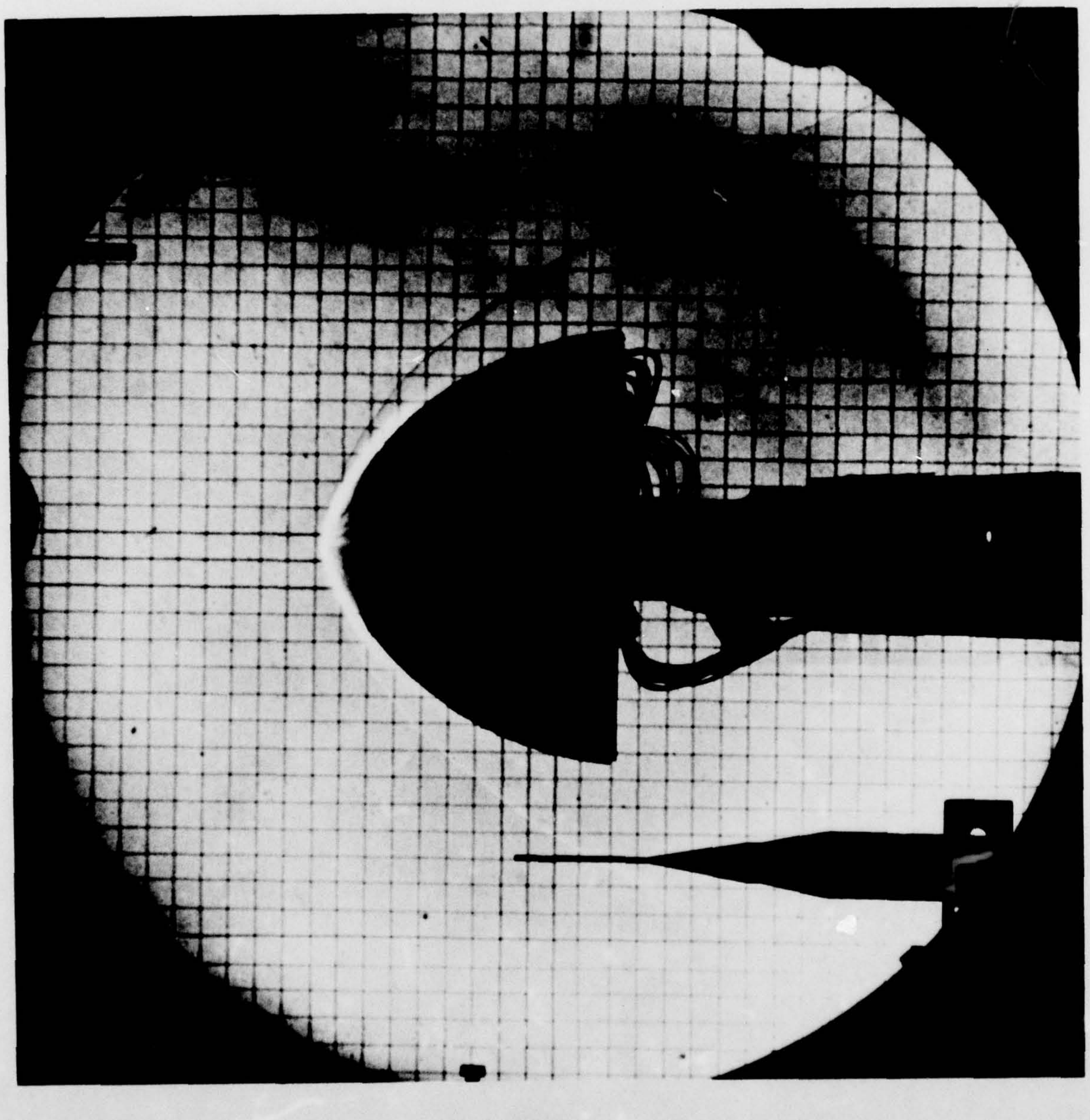

Figure 17

Schlieren Flow Field
Run No. 580 - Model K(R)
$M_\infty = 19.7$, $Re_\infty = 3.0 \times 10^6/ft$, $\alpha = +3^\circ$

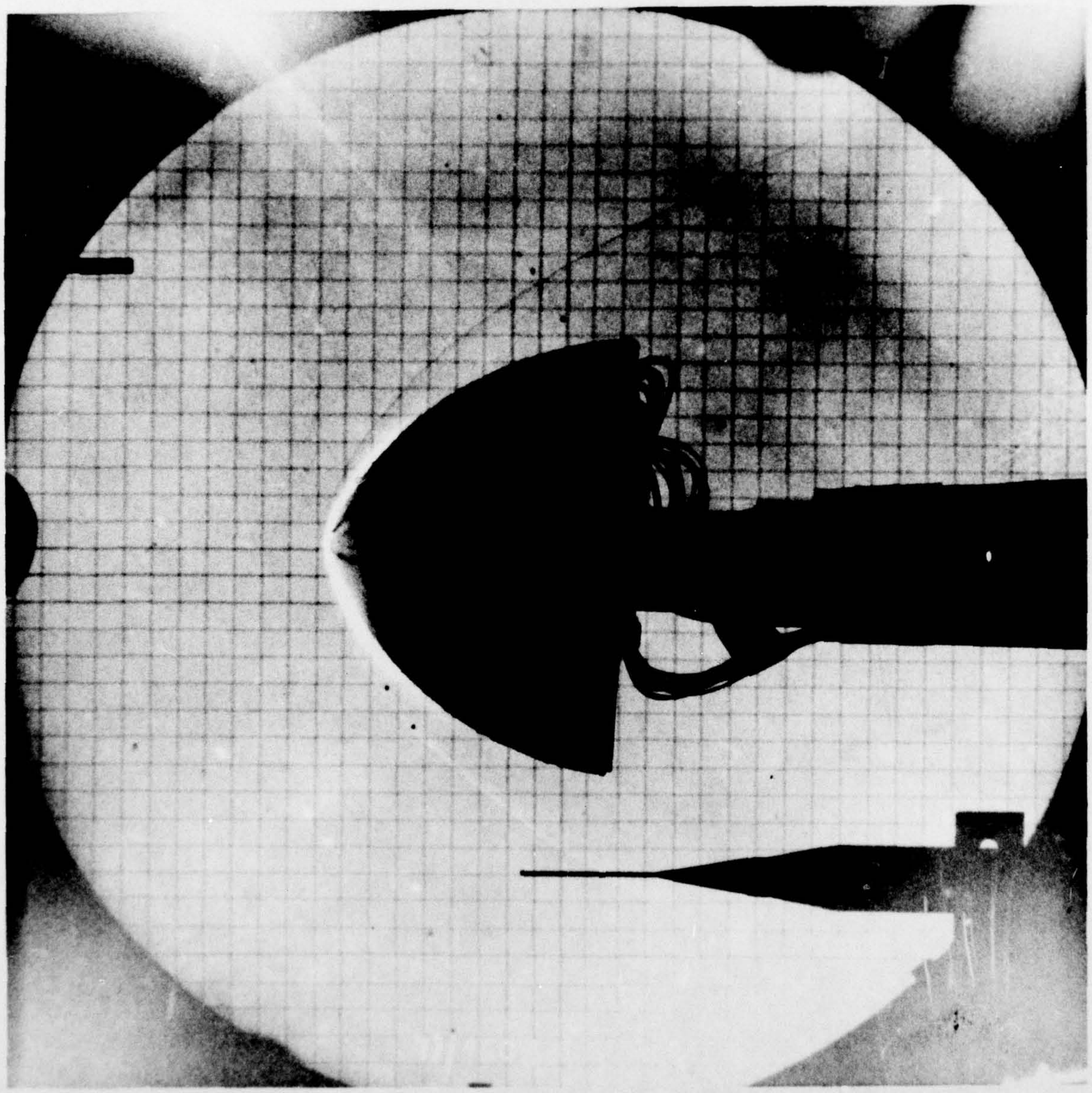

Figure 18

Schlieren Flow Field
Run No. 581 - Model K(R)
$M_\infty = 19.6$, $Re_\infty = 3.1 \times 10^6$/ft, $\alpha = -3^\circ$

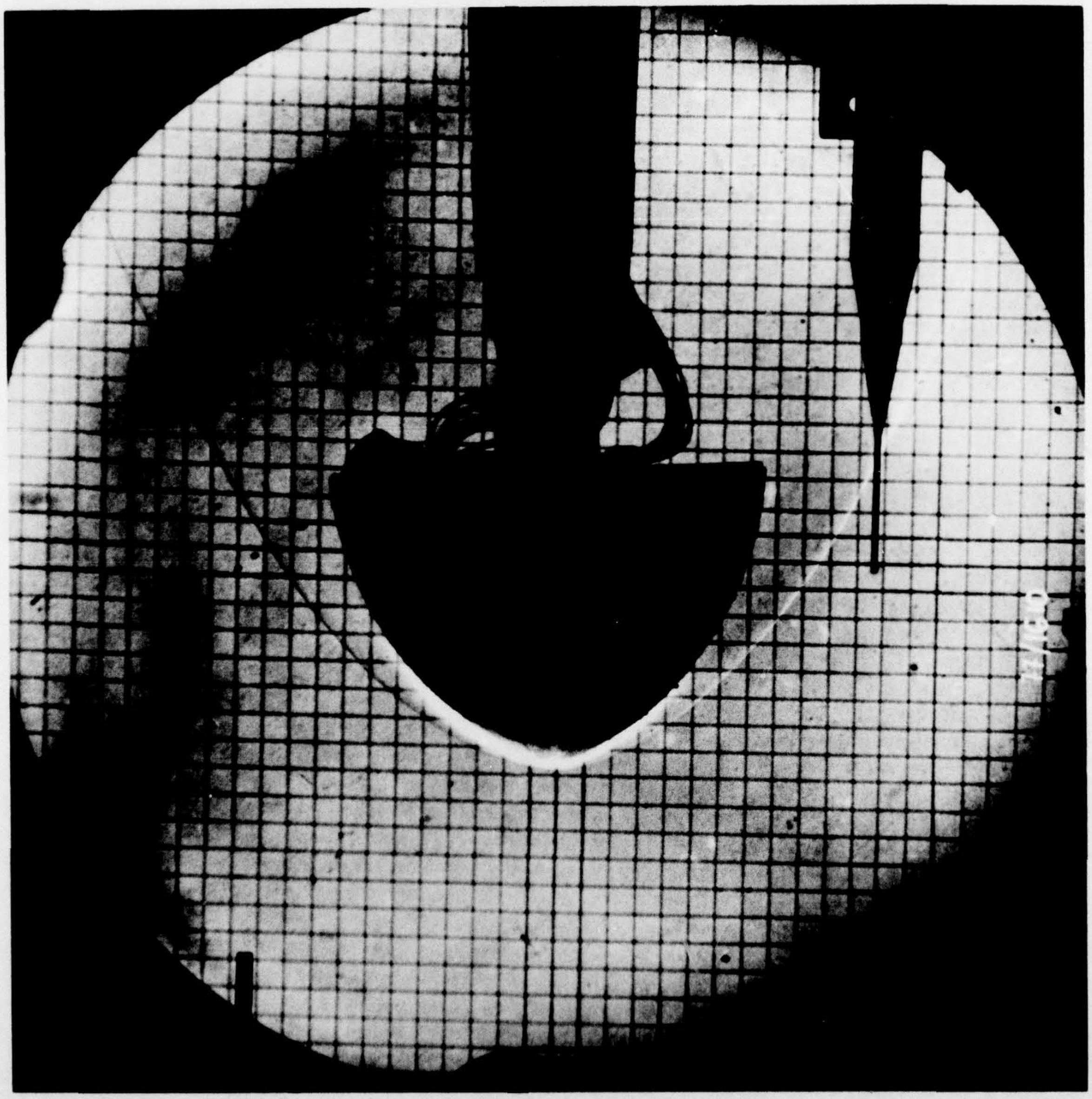

Figure 19

Schlieren Flow Field
Run No. 582 - Model K(R)
$M_\infty = 16.0$, $Re_\infty = 9.2 \times 10^6/\text{ft}$, $\alpha = -3^\circ$

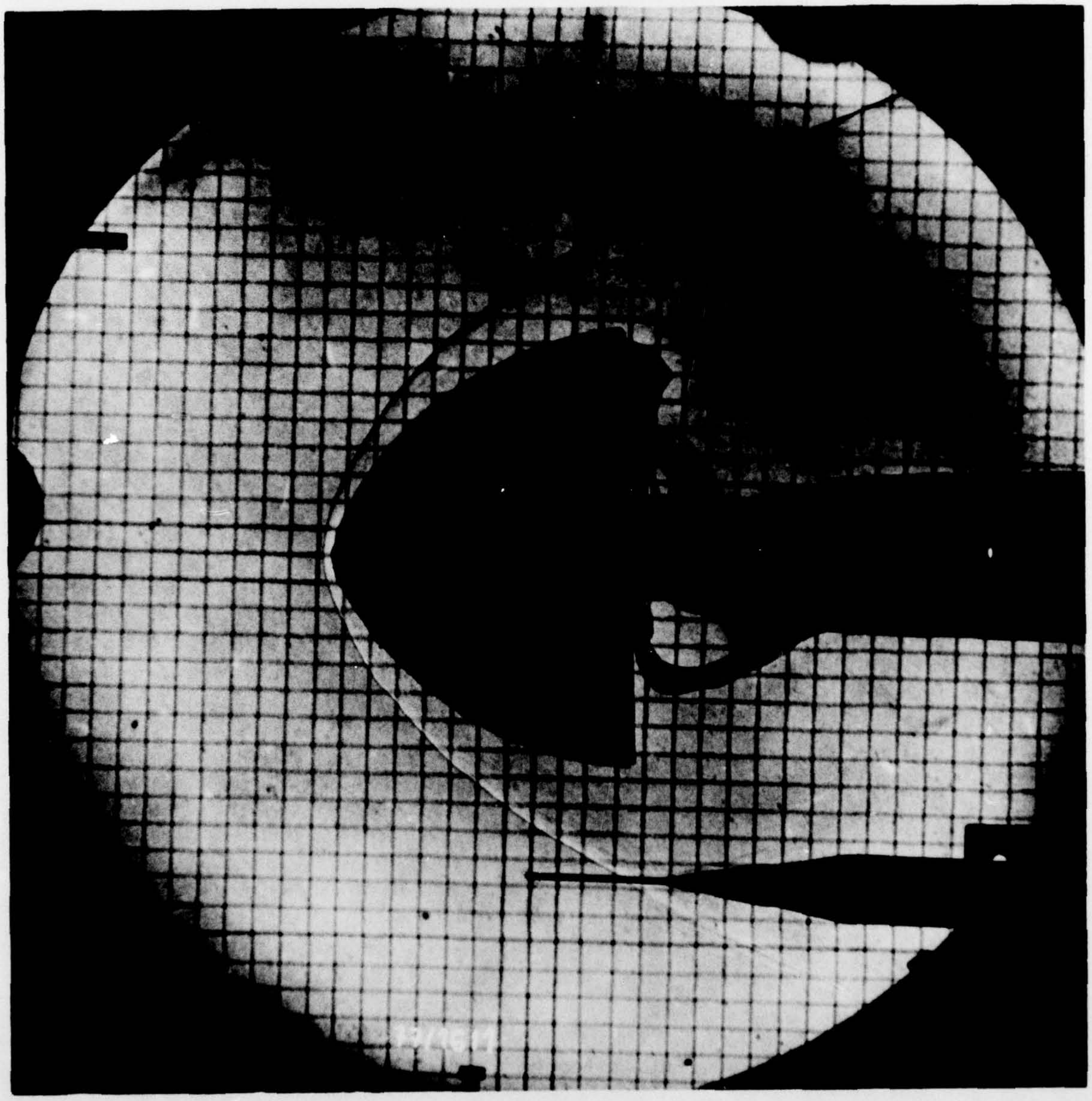

Figure 20

Schlieren Flow Field
Run No. 583 - Model K(R)
$M_{\infty} = 16.0$, $Re_{\infty} = 9.6 \times 10^6/\text{ft}$, $\alpha = +3^\circ$